Final Report

on

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FATIGUE OF POLYMERS AND ORGANIC COMPOSITES

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Please note:

The enclosed report covers the period research up to August 31, 1993. This also marks the termination of the first year of this program in the second renewal period (beginning 1992) as well as the termination of this program at Brown University (due to the move of the PI from Brown University to MIT). A new continuation program is expected to begin at MIT effective September 1, 1993.

This report summarizes the scientific goals of the program, significant results to August 1993, and plans for the work to be continued at MIT.A list of publications and presentations is also enclosed. A detailed description of the work done up to the reporting period is given in the paper entitled, "Cyclic Stress Fields Ahead of Tension Fatigue Cracks in Amorphous Polymers" by L. Pruitt and S. Suresh, which is appended to the report.

A. Description of Scientific Research Goals

This project is concerned with detailed experimental investigations of cyclic damage evolution and of the development of cyclic ``plastic'' zones ahead of fatigue cracks in polymers subjected to cyclic compression and cyclic tension-compression loads. The implications of such cyclic damage will be examined for a variety of fatigue phenomena including crack closure and variable amplitude fatigue. The fundamental studies will include transmission electron microscopy of near-tip deformation and damage, laser interferometry and quantitative photoelasticity on model systems for a wide range of mechanical loading conditions (i.e., frequency, load ratio, and tension and/or compression cycling). The information derived from the experimental program will also be used to develop conceptual and quantitative life prediction models including reliability analyses. Another major extension of the proposed work will be to experimentally document of cyclic near-fields for a fatigue crack perpendicularly approaching a metal-polymer bimaterial interface and to determine the conditions for the continued advance, acceleration or arrest of the crack as a result of crack-tip/interface interactions.

B. Significant Results During the Past Year

1. During the last year, we have conducted direct and in situ measurements of cyclic stress fields ahead of fatigue flaws in a photoelastic resin subjected to far-field cyclic compression loading. Photoelasticity and Mach-Zehnder laser interferometry experiments conducted on single edge-notched plates of a photoelastic resin were used to determine the residual stresses within the near-tip damage zone during the inception and subcritical growth of the fatigue flaw from the stress concentration.

2. Quantitative analyses of the relevant stress components at the notch-tip were used to establish a link between the evolution of cyclic near-tip fields and the conditions for the onset and advance of fatigue flaws.

3. Transmission electron microscopy observations were made for a rubber-toughened polystyrene to illustrate how the residual tensile stresses developing within the cyclic damage zone cause crazes to form along the plane of the fatigue crack, in a direction normal to the far-field compression axis. This result provides conclusive experimental documentation of the evolution of residual tensile stresses ahead of notches subjected to far-field cyclic compression.

4. A series of systematic experiments on the effects of mean stress on fatigue fracture was conducted, and the results of the experiments were rationalized with the aid of the near-tip cyclic stress measurements.

5. The applicability of the results of this study to a broad range of materials, including crystalline metals and ceramics, semicrystalline and amorphous polymers, and composites, was demonstrated. Furthermore the implications of the present results for orthopedic applications (specifically, for the use of ultrahigh molecular weight polyethylene in total hip or knee replacement components) has also been demonstrated.

List of Publications/Reports/Presentations

1. Papers Published in Refereed Journals

1. L. Pruitt and S. Suresh, "Cyclic stress fields for fatigue cracks in amorphous solids: Experimental Measurements and Their Implications", Philosophical Magazine A, vol. 67, pp. 1219-1245, 1993.
2. L. Pruitt, J.-H. Koo, C. Rimnac and S. Suresh, "Fatigue crack growth in ultrahigh molecular weight polyethylene under cyclic compression", J. of Orthopedic Res., submitted Sept. 1993.

2. Non-Refereed Publications and Published Technical Reports

1. L. Pruitt, "Cyclic damage ahead of fatigue cracks in polymers: Theory, experiments and applications", Ph.D. Thesis, Brown University, May 1993.

3. Presentations

a. Invited

1. S. Suresh, "Fatigue at Interfaces", Invited Lecture, International Symposium on Fatigue of Advanced Materials, TMS Annual Meeting, Denver, Feb. 1993.
2. S. Suresh, Keynote Lecture at Fatigue '93, Montreal, Canada, May 1993.

b. Contributed

1. L. Pruitt, C. Bull and S. Suresh, "Fatigue crack tip damage and stress fields in polymers and polymeric composites", in Fatigue 93, Edited by J.-P. Bailon and J.I. Dickson, MCEP, Birmingham, UK, vol. III, pp. 1349-1354, 1993.

4. Books (and sections thereof)

1. S. Suresh, "Cyclic Deformation and Fatigue", in Materials Science and Technology, Plastic Deformation and Fracture of Materials, vol. 6, pp. 509-563, VCH, Germany, 1993.

2. S. Suresh, "Fatigue of Materials", Chinese Translation of the Book originally published by Cambridge University Press, Chinese Academy of Sciences, Shenyang, 1993.